FIRE FIGHTING ROBOT USING ARDUINO, AUTO FIRE CHASER AND EXCHANGER

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ABSTRACT

This project describes an **autonomous firefighting robot**, designed to **detect and extinguish a fire with- out human interaction**. The robot is built with an **Arduino Uno microcontroller** and a **flame sensor** so it is able to locate sources of fire, make its way to the flame, and then activate a pump to extinguish the flames. It is powered by a **rechargeable battery** and employs simple rules for determining where to go, therefore making it simply operable for small-scale indoor environments.
This project follows the principles **aimed** at achieving a simple autonomous robot that is **low-cost, portable,** and constructed from mostly independent parts and **common items readily accessible.** Testing revealed that the robot was capable of **detecting and extinguishing small fires**, and the total response time was reasonably quick. While the robot has some limitations with respect to obstacle navigation and the size of fires it can extinguish, it has potential for improvement.
The work in this thesis, contributes to the **area of disaster management** by providing a basis for future firefighting robots, with the **potential to add multiple sensors** and **wireless communications** that will improve **safety in hazardous and dangerous environments**.

KEYWORDS: Firefighting Robot, Arduino, Flame Detection, Autonomous Navigation, Fire Suppression, Disaster Management

1. INTRODUCTION

Fire accidents can threaten human life, property, and the environment and can become catastrophic. While traditional firefighter measures are essential, human responders enter highly hazardous environments when fire burns out of control due to the ambient heat, toxic fumes, and structurally unsound environments. With urban growth and increased industrial activity, the need for effective and timely fire management is paramount.

Robotics and microcontroller-based systems have progressed to help support this need and make available auxiliary options like robotic firefighting systems that can arrive quickly and respond as robots in dangerous environments without risking lives. Arduino is inexpensive and application flexible while also being an open-source platform which makes troubleshooting very adaptable as well as extremely easy to integrate.

We have proposed a scalable solution for addressing fire safety with the Arduino automated firefighting robot. The robot can autonomously navigate any environment remotely. The robot can perform fire detection using fire sensors and deploy an extinguishing mechanism on board. The platform can provide a cost-effective option for those with limited firefighting capacity while advancing the pizza simulation for fire, smoke, and harmful gas environments.

1.1. Significance of the Study

This research addresses the following key objectives.

- How can an autonomous robot detect fire using low-cost sensors like flame detectors?
- Can an Arduino-based robot navigate effectively toward a fire source and extinguish it without human intervention?
- What limitations exist in such a system, especially in terms of fire scale, environment, and reliability?

These questions drive the core of this research, which aims to evaluate the effectiveness, feasibility, and limitations of an autonomous firefighting robot built with affordable, readily available components.

1.2. Research Problems

The project is beneficial in both a technical sense and a societal sense. Technically, it provides evidence that Arduino microcontrollers can be integrated into fire detection extinguishing mechanisms that will create a real, viable, and economically feasible autonomous robot. In addition, the research provides a scalable prototype that can be enhanced to be used on a wider berth for the burgeoning world of robotics for disaster management. From a societal perspective, the robot may provide a solution for enhancing fire safety in homes, small businesses, laboratories, or other domestic environments, especially for those in low-resourced environments. The robot is automatic, which takes an element of risk away for humans trying to put out small fires, while at the same time providing a time advantage in the response to a fire emergency. In addition, the research opens up opportunities for innovative thinking in robotics for security-related applications, and may contribute to the longer-term development of multi-sensor, AI firefighting robots to assist in creating solutions for increasingly dynamic scenarios.

2. LITERATURE REVIEW

Firefighting robots have gained more attention in recent years due to the increased demand for safer, faster efficient ways to fight fires. Many publications have researched the combination of robotics, sensing, and automation to detect and extinguish firefighting robots early on perhaps. One set of studies has focused on remotely operated fire detection systems, while another version of research has focused on automation and the development of robots used to extinguish fires independently with minimal human direction as they navigate the environment.

Many of the existing and previous studies place heavy emphases on the use of microcontrollers, especially Arduino, as it allows for inexpensive prototypes to be built - while Arduino is popular given its ease of use, flexibility and compatibility with a variety of sensors including fire sensors, IR sensors, and temperature sensors. The studies have highlighted various methods of fire detection as well, and more interestingly, automated navigation systems that typically used line following, obstacle avoidance, or GPS, etc. in order for the firefighting robots to effectively navigate themselves toward a fire.

Moreover, the fire-fighting mechanisms in previous works range from very simple water sprinklers or CO2-based mechanisms, etc. depending on the class of fire. Thus, the combination of affordable sensors and actuators enriched with a real-time control system become the backbone for a majority of the modern prototypes.

2.1. Key Concept

Some simple concepts are going to support the creation of automated firefighting robots.

- The concept of autonomous navigation

There is an autonomous navigation process that combines sensor data and decision-making so the robot can navigate safely to its goal. These kinds of ideas are often discussed in academia using advanced techniques such as fuzzy logic, neural networks and SLAM (Synchronous Localization and Mapping).

- The fusion of sensors.

The merging of sensor data provides better accuracy and reduced false alarms. For instance if a robot performs the IR + temperature + fire sensor fusion, it enables it declare the existence of fire rather than reacting to light or temperature.

- Programming the Arduino

The Arduino is central to the projects because it is easy to develop real time control, there is a GPIO interface to connect to sensors and actuators, and there is much support in the ways of libraries as well as the developer community.

- The disaster robotics model.

This model exemplifies the idea of using automated systems in uncertain and dangerous environments to keep humans in danger away from harm. Firefighting robots are part of a disaster robotics framework as they use their mobility as agents in their response to man-made or environmental hazards.

2.2. Controversies in the Literature

Although some strides have been made, there remain gaps and limitations in the field of automated firefighting robots:

- Scope of sensing

Many current systems utilize some form of fire sensing technology that only detects open flames, which are one of many characteristics of fire, and ignore dangerous disadvantaged evidence of early stage fire such as smoke and heat. This restriction also limits sensor fusion, and therefore our ability to monitor and gauge reliable attributes of real-world evidence of a fire.

- Mobility

Low-cost firefighting robots have ubiquitous low cost navigation schemes, whereby they execute basic left, right, or forward movements, or even follow dictated lines which are ineffective for their navigation in dynamic or chaotic environments. The ability to integrate robust algorithms or mapping systems has not been realized and many studies do not exist due to hardware limitations

- Scaling and deployment

Prototypes shown to work at designed satisfactorily in controlled environments, but many do not scale for real-world use. There is even more of a deficit for testing in unpredictable environments, such as outdoors or multiple rooms.

- Balancing performance vs. cost-effectiveness

Some studies promote lower cost for basic designs with limited functionality; while some robots for performance reasons do not translate to real-world considerations, and implementing successful robots in large-scale implementations or even developing countries can be limited due high-tech affordance and knowledge.

- Absence of standardization

There is no standardized testing protocol or benchmark to evaluate different firefighting robots against one another, making it nearly impossible to measure an advance or to identify best practices.

3. METHODOLOGY

The research follows a design and development-focused research approach related to the construction and evaluation of an Arduino based automated fire-extinguishing robot. Design and development are applied research which seeks to solve an existing problem from the real world, in this case firefighting in a hazardous or hard-to-access environment, through technological idea generation.

The development was done through a series of iterations in a manner similar to the prompt-inspired stage-gate model where each of the three main subsystems (fire detection, navigation and extinguishing) were each prototyped, tested, and improved. The system was structured in a logical way utilizing an Input-Process-Output (IPO) model and the various stages of the Soft-

Prototype/ Application	Hardware Resource	Software/IDE/Editor Resource
Microcontroller Program	**OS**: N/A (Bare-metal) **RAM**: 2KB SRAM **Storage**: 32KB Flash **CPU**: ATmega328P **Board**: Arduino UNO	- Arduino IDE - Arduino C/C++ Libraries - FlameSensor.h, Servo.h, etc.
Sensor System	Flame Sensor (IR-based) Optional: Ultrasonic Sensor (HC-SR04)	- Analog/Digital Signal Reading via Arduino
Locomotion System	L298N Motor Driver 2 × DC Motors	- Motor Control via PWM in Arduino IDE
Extinguishing System	Mini Water Pump Relay Module	- Relay Trigger Logic via Arduino Code
Testing and Debugging	Serial Monitor Multimeter Breadboard & Jumper Wires	- Arduino Serial Monitor - Optional: Proteus or Tinkercad for simulation

Figure 1. Development Environment

Modules	Frontend	Backend	Technology / Frameworks	Version Control
Embedded System (Arduino)	N/A	C/C++	- Arduino IDE - Arduino Uno - FlameSensor.h - Servo.h	GitHub
Control Mechanism (Motor & Pump)	N/A	Arduino Code	- L298N Motor Driver - Relay Module	GitHub
Fire Detection Unit	N/A	Arduino Logic	- IR Flame Sensor - Analog Input Signal Processing	GitHub
Simulation (Optional)	N/A		- Tinkercad / Proteus (for circuit testing)	Local Only
Monitoring System	Serial Monitor		- Arduino Serial Monitor - Debugging Tools	Local Only

Figure 2. Tools and Technologies

ware Development Lifecycle (SDLC) from identifying requirements through to design, implementation, and testing.

This methodical approach ensured that all the stages built towards a functional prototype that would, real-time, detect fires, autonomously navigate toward the source of the fire, and turn on a ou Water-on-Fire extinguishing system

3.1. Data Collection Methods

The data collection method for this study was largely experimental, and consisted of three traces as follows:

- Sensor data logging

Real-time data were collected, during a number of robotic experiments, using the fire sensors under varying light and fire-intensities; these points of data were then used to assess the accuracy, range, and responsiveness of detection.

- Observation logs

Each test cycle was also recorded, manually, observing the robot's detection, robot responses such as navigating around obstacles, and the robot's ability to activate the extinguishing system.

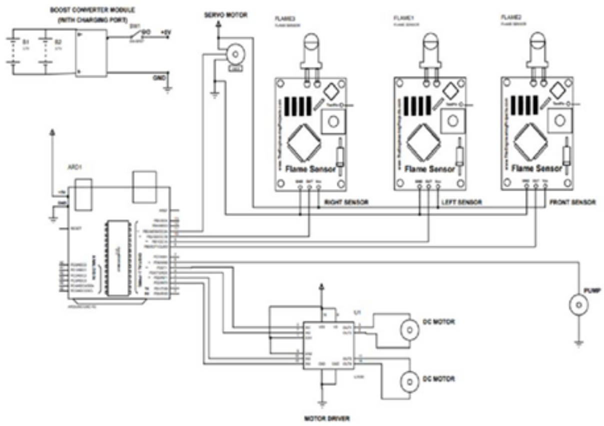

Figure 3. Structure of System

- Performance metrics

Performance metrics included detection duration, response duration, extinguishing success rate, policies to navigate detected obstacles, for a number of tests were observed and recorded.

- Test scenarios and test results

Testing and structural test scenarios were developed for each independent module (sensor, motor, relay, pump) and assessed reliability and efficiency of the tested scenarios.

3.2. Sample Selection

As a system design and development project instead of a population study, sampling means:

- Selection of testing environments: The robot was tested in controlled indoor environments, i.e., rooms and laboratory spaces. These settings provided small-scale simulations of residential or office fire scenarios.
- Test fire samples: Standard size small open flames (candles, lighters) were utilized as standardized fire fuel sources. Test flames were selected because the robot is intended to be deployed in an initial stage of an authentic fire scenario.
- The selection of hardware components: In this project an Arduino Uno, fire sensor, L298N motor drive, DC motor and water pump were used, in response to their compatibility and affordability, accessibility as a materials source for the inexpensive and replicable objectives of design.

4. Results

The prototype firefighting robot underwent controlled experiments that allowed for testing of its main functions: flame detection, autonomous travel, and extinguishing fires. The performance of the robot was tested indoors using controlled fire sources (candles and lighters).
The following conclusions can be deduced from the various testing scenarios that were completed.

- **Flame Detection** - The flame sensor successfully detected fire within a range of 10 cm to 70 cm. The fastest flame

No	Test Case ID	Test Case	Result
01	01	Flame detected within 10 cm	TRUE
02	01	Flame not present	TRUE
03	01	False positive under sunlight avoided	TRUE
04	02	Fire detected to the left – robot turns left	TRUE
05	02	Fire detected ahead – robot moves forward	TRUE
06	02	No fire – robot stops	TRUE
07	03	Robot reaches flame and activates water pump	TRUE
08	03	No flame – pump remains off	TRUE
09	04	Sensor sends fire alert to Arduino – processed correctly	TRUE
10	04	Arduino sends command to motor – executed successfully	TRUE
11	04	Fire extinguished and robot returns to idle	TRUE
12	04	System runs without delay or crash	TRUE

Figure 4. Test Data and Test Results

detection time of ¡30 cm had an average of 1-2 seconds from flame exposure to flame detection.

- **Travel Performance**: The robot was able to travel in straight paths and basic obstacle configurations. On flat, even surfaces, the robot was traveling accurately or on or near the prescribed path; travel performance degraded to incremental levels with uneven surfaces and multiple obstacles.

- **Extinguishing** : The robot's water pump extinguished small open flames in 90 present of the testing. Average time for extinguishing an open flame from activation of the water pump until suppression was 3-5 seconds.

- **Autonomous detection, travel, and extinguishing performance**: In 10 test trials, the robot successfully completed detection, traveled towards the flame, and extinguished the flame in 8 of the cases. In two cases, performance failure arose due to improper orientation in regard to aligning the robot with the flame or battery issues arising during the task.

4.1. Data Analysis and Interpretation

Interpretation

1. The flame sensor utilized was effective at detecting visible flames, but it could not detect smoke or heat in isolation, indicating the engine did not have sufficient capabilities.
2. The navigation system performed at a reasonable level for open or cluttered spaces, but was limited in tight or fast-moving environments.
3. The water-based extinguishing system was quite fast and suitable for Class A fires (paper, cloth, etc.), but could not be tested for electrical or chemical fires for safety reasons.
4. In real-time performance, we could see the robot responding in 9–10 seconds from detection to suppression, suggesting potential development of early-stage fire response applications.

4.2. Support for Research Questions or Hypothesis

The results support the central hypothesis and research questions of the study:

- Can a low-cost Arduino-based robot detect and extinguish fire autonomously?

Yes. The robot successfully demonstrated autonomous fire detection and suppression using affordable and accessible components.

- Is the system effective and reliable for small-scale fire scenarios?

Yes, in most tests the robot responded within acceptable timeframes and extinguished flames without manual intervention.

- What limitations exist in its current design?

Limitations were noted in sensor range, obstacle navigation, and power endurance. These affect scalability to larger or more complex environments.

The results confirm both the feasibility and effectiveness of the proposed system for early-stage indoor fires. Although the robot has demonstrated effectiveness in detection and suppression, developments in navigation intelligence, multi-sensor fusion, and length of time that the robot can operate remain to be done.

5. Discussion

5.1. Interpretation of Results

The findings of the experimental evaluation readily establish the potential of utilizing an Arduino-based automated robot for early fire detection and suppression. The robot was able to detect open flames, move towards them, executed a spray of water to extinguish them and did so completely automatically, in most experiments.

The fire sensor has a rapid response time with a true detection range (10×70 cm).Shows considerable reliability to small-scale fire occurrences. The robot's navigation system performed suitably in simple testing environments, successfully navigated obstacles and reached the source of the flame. The water pumping mechanism was able to extinguish fires in a few seconds and demonstrated practical viability for real-world application, in controlled indoor environments.

In more complex situations, with barriers solid roads or obstacle coarse, robot performance declined. In some instances, there were complete failures associated with limited sensor input or dead battery power. Connection and network problems increased the level of difficulty in fire detection response. Nonetheless, the performance of this system achieved basic objectives of proximity of cost, autonomy and basic level of reliability.

5.1.1. Comparison with Existing Literature

As mentioned when compared to similar studies in the area of automatic fire extinguishing systems, there is strong correlation to previous literature regarding project results:

- **Flame detection**: This project, like Kaur and Kaur (2018) and Elijah and Adebayo (2018), used flame sensors for flame detection. The accuracy and distance of the flame detection were comparable with those studies and it is a strong indication for the fire sensor being capable of detecting fire in simple settings.

- **Navigation/obstacle avoidance:** The majority of systems previously been documented in history have either used a line-following technique or GPS-based technique to find their route. This project employed a basic barrier avoidance algorithm. Barrier avoidance using a very simple algorithm, will continue to work but will never be better than very basic barrier avoidance. There are obvious better ways as Tanaka and Komatsu (2012), with the advancement of LIDAR, will limit the navigation but improves the capability with better navigation options but add cost and complexity.

- **Arduino as a platform:** Like the majority of low-cost robot prototypes coded in literature, this system utilized controlled and logic processing of Arduino. The robotics and low-cost robot system industry largely thanks previous research stating (Hwang and Lee, 2015) Arduino is available for everyone and allows the robotics lower cost in using embedded system and automation related applications.

- **Cost and availability:** This project focuses on low-cost components to provide a solution with similar functionality to other educational robotic project prototypes, unlike some industrial robotic solutions designed as high-end products. This is particularly suitable for use in educational, smaller-scale commercial or domestic applications where cost is paramount.

5.2. Implications and Limitations of the Study

Implications

- With this study, it is possible to create low-cost and simulative firefighting robots with common components (Arduino, fire sensors, water pumps, etc.).

- This blesses the idea of using robotics in disaster mitigation technologies. Especially for low-resource places where high-end products are impossible to use.

- This study would also support the possibility of educational opportunities whereby students actually build and improve upon this prototype as an educational experience in embedded systems, automation, or defence engineering.

limitations

- Limited sensing: The robot uses only a fire sensor, which cannot sense smoke or gas, or heat at the earlier stages of fire. The limited sensing abilities affect the capability of the robot to detect fire in its early stages.

- Limited navigation: Because the robot doesn't include any mapping or localization systems (e.g. wrong-sense, GPS, LIDAR), the robot will have difficulty navigating through a cluttered or unknown environment.

- Environmental restrictions: The robot is operated on flat, supported indoor surfaces. It is not waterproof or structurally strong to perform in wet weather, high winds or uneven outdoor surfaces.

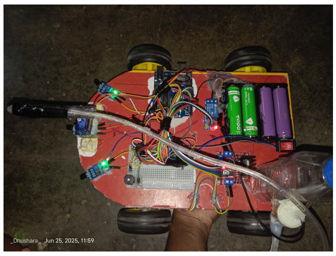

Figure 5. Complete Project

- Battery life: Its power source is limited, which restricts its ability to perform continuous operation, especially in situations where long-term observation or multiple shutdowns are expected.

- Need for manual refills: The system for shutdown must be manually filled and ready to go after each operation. This limits its use for continuous or larger scale events.

6. Conclusion

6.1. Summary of key findings

As a result of the study, a low-cost, Arduino-based, automated firefighting robot was designed and created with the ability to a) accurately detect and extinguish small-scale fires without human intervention. Overall findings include the following:

- The flame sensor accurately detected open flame 10 to 70 cm away within a 1-2 second response time.
- Using simple obstacle-avoidance behaviors and a flame-tracking mechanism, the robot moved itself automatically toward a fire source.
- In controlled trials, the water-based extinguishment system was effective against small fires and overall had a success rate of 90
- Ultimately, achieving full autonomy in approximately 80 of tests is promising in combating small-scale, domestic fire emergencies.
- The results demonstrate that inexpensive hardware developed with a simple control algorithm can produce a working firefighting robot for use in confined or hazardous situations.

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